Quarterly Progress Report

Technical and Financial

Hypoxia, Monitoring, and Mitigation System

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Submitted By

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14. ABSTRACT
The Hypoxia Monitoring, Alert and Mitigation System (HAMS) program is progressing as expected. The program consists of two baseline tasks and three optional task. Work is almost complete on Task 1. Task 2 was started in May. Optional Tasks 3, 4 and 5 have not been exercised. The second iteration of the arm mounted prototype is being fabricated and tested that includes a multi-site approach. This approach adds redundancy to the sensor network that will further enhance the system and mitigates risk for the program moving forward. We recommend that the program continue as scheduled.

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1.0 Summary

This quarterly progress report discusses the technical and financial program status for the period of April 2015 through June 2015. This is the third quarterly report on the program.

The Hypoxia Monitoring, Alert and Mitigation System (HAMS) program is progressing as expected with no significant technical issues to report.

The program consists of two baseline tasks and three optional task:

1. Task 1 - Initial Prototypes
2. Task 2 - Design and Development Evolution
3. *Task 3 - Production Ready HW/SW (Option)*
4. *Task 4 - Preliminary Human Testing of SpO2 Sensor and Electronics (Option)*
5. *Task 5 - Final Human Testing of SpO2 Sensor and Electronics (Option)*

Work continues on Task 1, Task 2 began in May and optional Tasks 3, 4 and 5 have not been exercised.

Sensor definition testing continued on the custom pulse-ox design. Additional refinement on the pulse rate and SpO2 algorithm development was also accomplished. The electronics and software development made significant adjustments to accommodate the upgrade from the Freescale K21 to the K70 processor. New circuit boards we designed and fabricated. The software code was modified. The upgrade increased processing power to handle additional communication/interface ports and processing of the waveform data.

Additional hypobaric chamber data was uploaded to the HAMS FTP site. The relationships between sea level, 10K, 18K and 25K were analyzed. The introduction of degradation assessment categories was considered and discussed based on the Active Node prediction function output from the conscious model.

A project review was held before the start of the Aerospace medical Association Meeting in Orlando, FL on May 10, 2015. The meeting was conducted by Dr. Shender and attended by Cesar Gradilla and Sean Mahoney from Athena GTX, Phil Whitely from CAI, Dr. Leon Hrebien from Drexel, Dr. Moshe Kam from New Jersey Institute of Technology, and Dr. Khalid Barazanji who is an Army interested party from USAARL and is the Branch Chief of Airworthiness Certification and Evaluation.

We recommend that the program continue as scheduled.

2.0 Introduction

Special Notice 14-SN-0002 outlined a research thrust entitled "Hypoxia Monitoring, Alert and Mitigation System" (HAMS) that was launched under the ONR BAA 14-001 Long Range Broad Agency Announcement (BAA) for Navy and Marine Corps Science and Technology. The primary technology areas of interest for full system development over the lifetime of the program are 1) detection/prediction algorithm, 2) sensing suite, 3) warning modalities, and 4) modes of mitigation. This Special Notice is a follow on to Special Notice 13-SN-0003, published in November 2012. Overall, HAMS must be compatible with multiple operational environments. The intent is to develop a modular prototype, with capabilities for 1) ground troops at altitude and 2) CASEVAC. The team of Athena GTX (Athena) and Criterion Analysis Incorporated (CAI) collaborated, proposed and won an award under this effort.

This quarterly progress report discusses the technical and financial program status for the period of April 2015 through June 2015. It is intended to inform the Program Officer and Administrative Contracting Officer of the technical and financial progress of the HAMS program. This is the first quarterly report on the program.

The program initially launched via Special notice 13-SN-0003 concentrated only on algorithm development. Now this follow-on effort will develop the hardware necessary to implement HAMS. In addition, more data to refine the algorithms and data analysis approaches will be gathered. Sensors which detect SpO2, pulse/pulse rate, ECG, and skin temperature will be researched and evaluated for integration feasibility with a tactile vibrator for alerting the user to the suspicion of growing hypoxia. Novel and non-traditional sensor locations and technologies will be investigated as they impact data and algorithm design issues, and advanced signal processing techniques applied, and compared in this program for extensive technology leveraging.

The goal is to provide optimal protection of military personnel and equipment via intelligent monitoring and adaptive modeling that accounts for individual differences in physiologic tolerance and provides a timely notification/warning such that personnel can take corrective action before missions are compromised or injuries are aggravated. HAMS will address cognitive and physiological workload at altitude and the dynamic impact of sustained high altitude operations. The effort under this program allows for iterative prototype development and testing to occur leading to an option for development of systems that are FDA cleared and ready for full field use.

3.0 Technical Progress

3.1 Task 1 – Initial Prototypes

3.1.1 Sensor(s) Definition

The custom pulse ox designed board leveraged from TI continued to be tested and associated algorithm(s) developed to obtain phyisiological information. The next steps are to miniaturize the module in order to develop an array of sensors for the arm unit. More development, data testing, and filtering for artifact in the signal will continue throughout the next reporting period that will leverage into the next revision of the design.

Figure 1: Pulse OX custom module

3.1.2 Enclosure Concept Definition

This reporting period we continued to develop conceptual 3D drawings for the wrist unit and updated a lower profile arm design based on component rearrangement. A display in the arm unit is still an option but can be removed to create an even lower profile design. Refinement and adjustment will continue based on feedback and development with sensors.

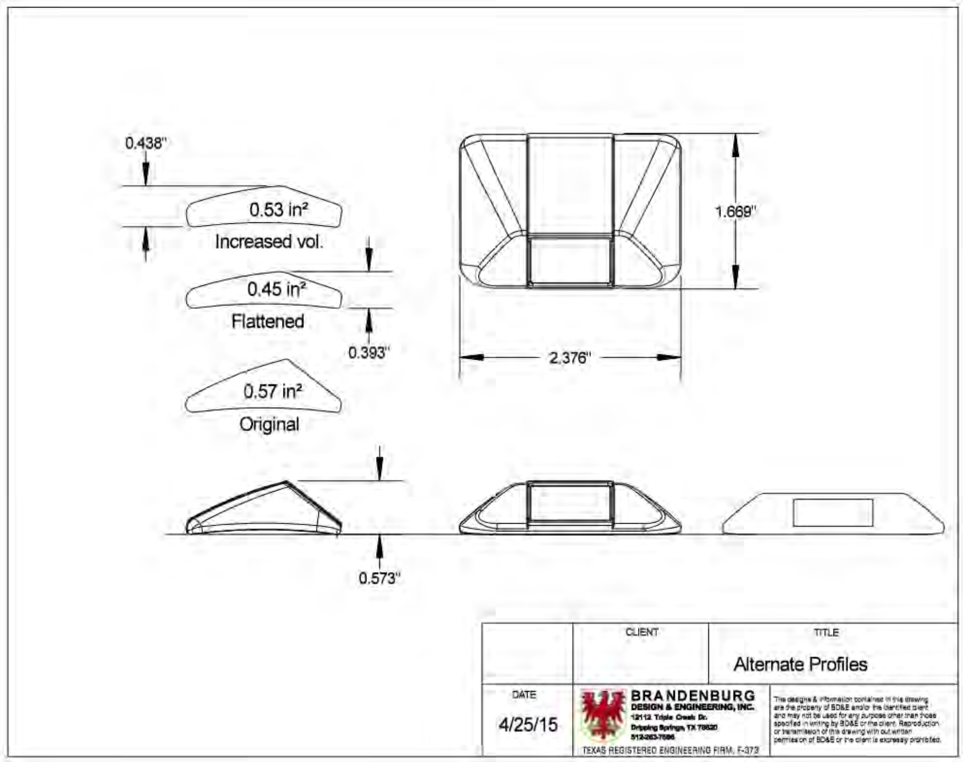


Figure 2: CAD drawings for enclosure options

Figure 3: CAD drawing for Arm unit concept

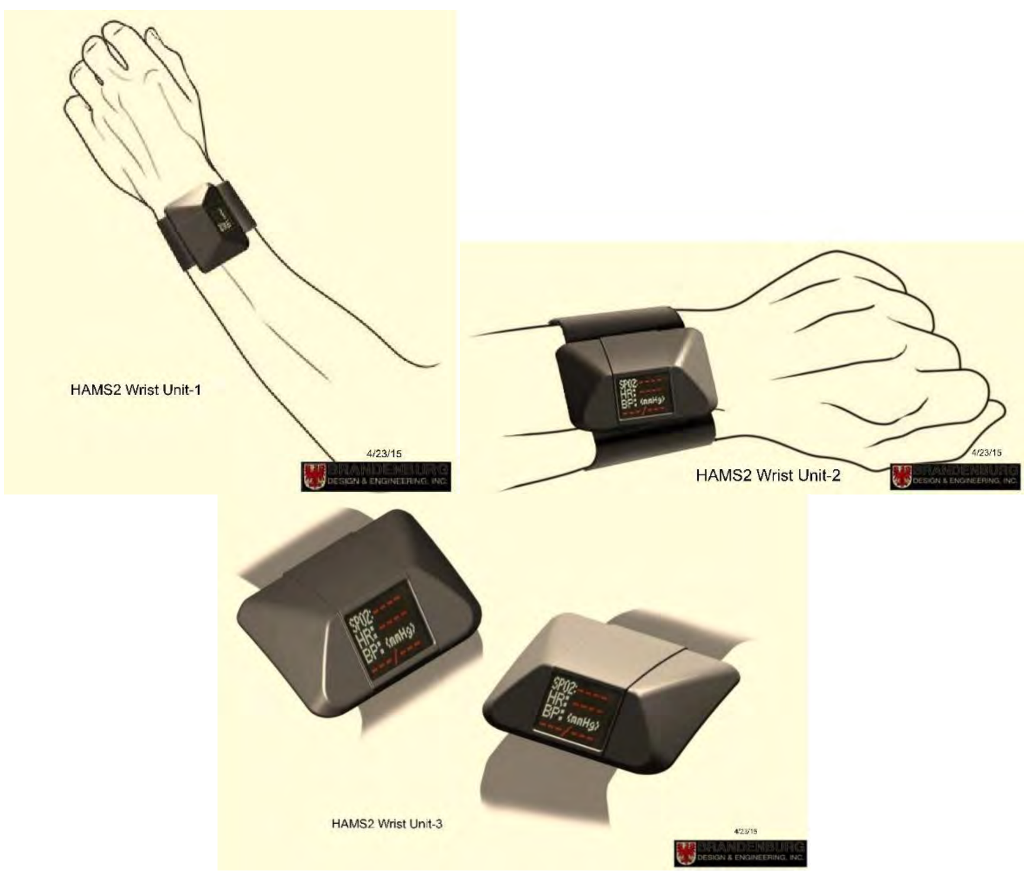


Figure 4: 3D drawings for wrist unit

Updates to 3D drawings were completed for the arm unit based on component definition and rearrangement in Figure 5. The below depicts the removal of the display from the arm unit allowing a lower profile design. This does not include the Pulse Ox detector array sensors that will interface to the arm unit within the band. Additional concepts were developed this reporting period as seen in Figure 8. The internal lab 3D printer will be used to build the concepts for form and layout testing in the next reporting period.

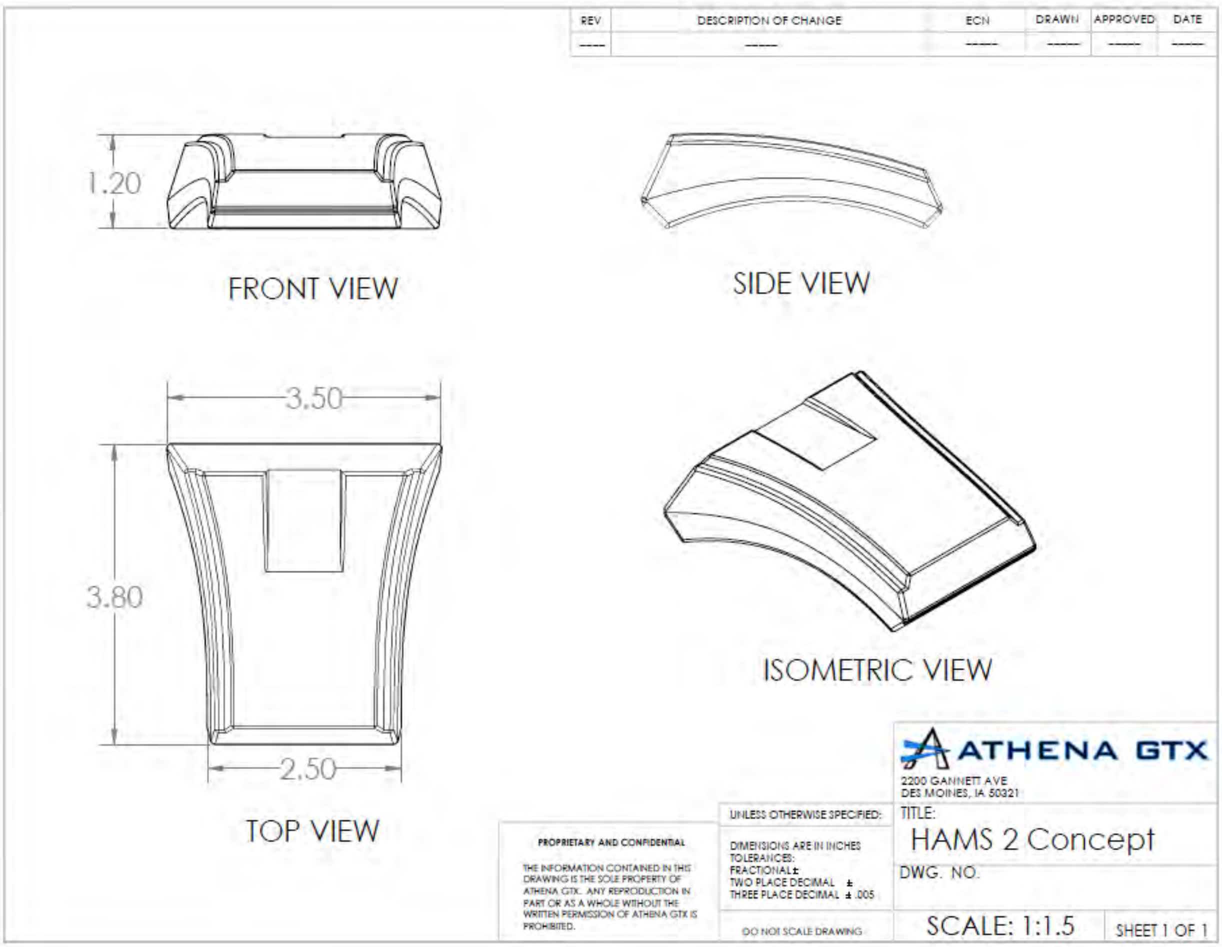


Figure 5: CAD drawing for arm enclosure

Using the CAD drawing from figure 5 an arm concept unit was built using the lab 3D printer seen in Figures 6-7. This concept will be delivered to the customer as a precursor to the functional prototype at the ONR FHP in July 2015. The focus with this enclosure was to envision a covering surface of the bicep medial side and ensuring that flexing the bicep would not be a problem. A compression sleeve is used to easily position the arm sensor and a strap as a secondary measure to adjust it to the arm. Adjustments will be made based on the final main PCB and Pulse Ox sensor PCB layouts.

Figure 6: Arm unit concept: Top View

Figure 7: Arm unit concept: Side View

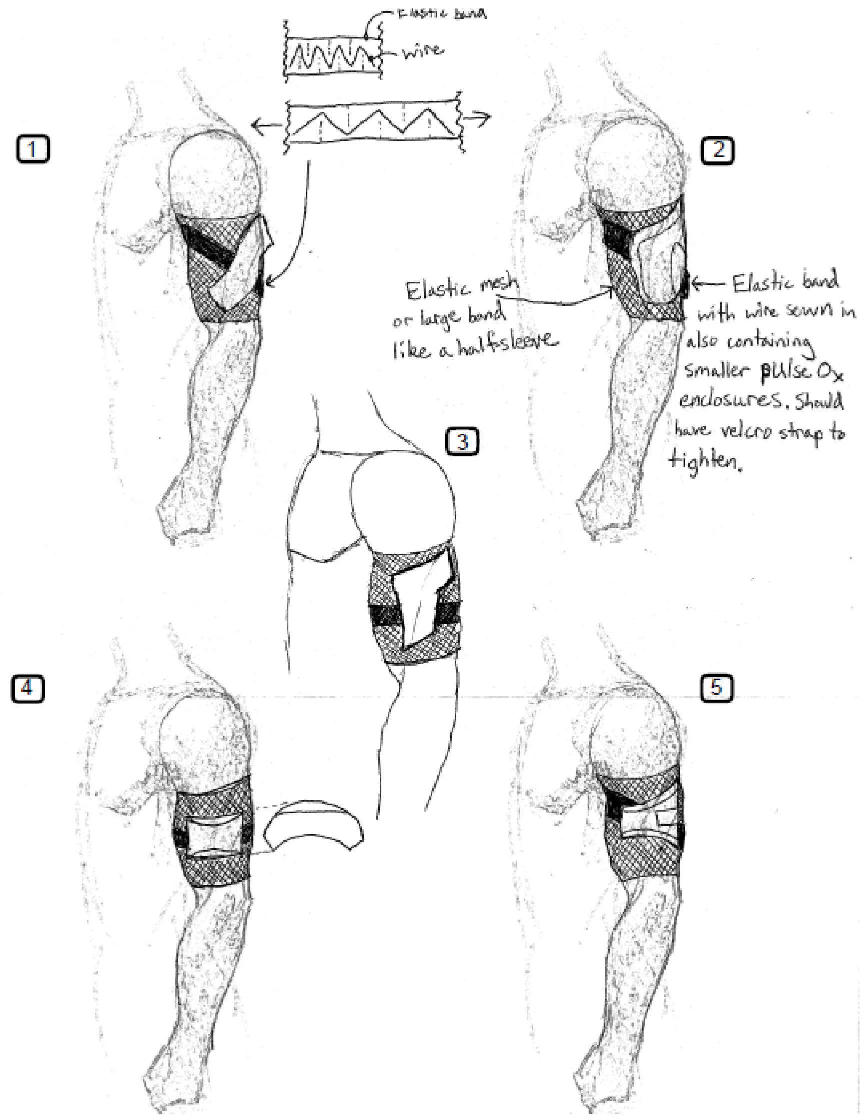


Figure 8: Sketch drawings for arm unit concept

3.1.3 Electronics Board Schematic and Layout

Throughout this reporting period the initial schematics were designed for the arm unit based on development board hardware and software testing. Preliminary schematics, schematic libraries and PCB footprints were designed based on testing with the Freescale K21 development tower system. Block diagram of the initial configuration is seen in Figure 9.

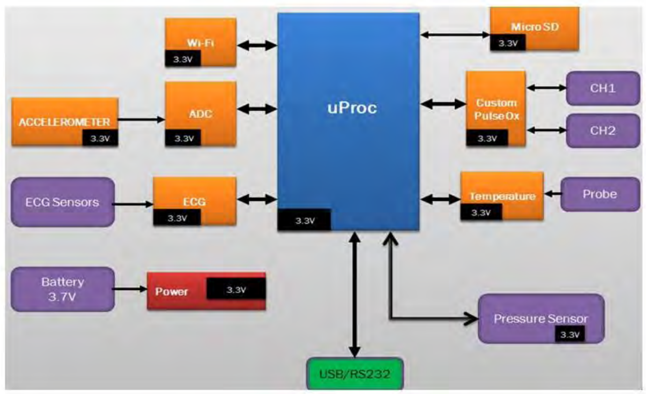


Figure 9: HAMS II Block Diagram: System w/ peripherals

Below are initial schematics for components of the system. These designs include the accelerometer, altimeter, ZigBee transmitter and charging circuit. Further tests with the Freescale K21 development tower system demonstrated limitations with the memory due to speed required to process the analog signals. The processor and memory were upgraded from the K21 to K70. This upgrade allowed additional ports for sensors, processing, and memory capability. Updated schematics, schematic libraries and a new PCB layout were created. Below is the PCB board layout (Figure 11) for the first prototype build with the upgraded components. Testing and performance on the overall system we be the focus throughout the next reporting period.

Project Logs for HAMS2	5/28/2015 12:57 PM	File folder	
Rev I	6/2/2015 9:29 AM	File folder	
SPO2	6/1/2015 8:46 AM	File folder	
Accelerometer Proto	5/28/2015 8:33 PM	Altium Schematic ...	42 KB
Accelerometer	5/28/2015 11:37 A...	Altium Schematic ...	42 KB
Altimeter Proto	5/28/2015 8:33 PM	Altium Schematic ...	27 KB
Altimeter	5/28/2015 11:38 A...	Altium Schematic ...	27 KB
Arm Unit	5/28/2015 11:30 A...	Protel PCB Docum...	84 KB
BLOCK Proto	5/28/2015 8:33 PM	Altium Schematic ...	34 KB
BLOCK	5/26/2015 5:15 PM	Altium Schematic ...	34 KB
ECG	6/15/2015 3:51 PM	Altium Schematic ...	400 KB
GenLib	6/12/2015 11:11 A...	Protel PCB Library	355 KB
HAMS2 Proto	5/28/2015 6:33 PM	Altium PCB Project	43 KB
HAMS2	5/28/2015 4:42 PM	Altium PCB Project	43 KB
HAMS2.PrjPcbStructure	5/28/2015 4:31 PM	PRJPCBSTRUCTUR...	2 KB
HAMS2	5/20/2015 5:50 PM	Altium Schematic ...	19 KB
MicroProcessor K21 Proto	5/28/2015 8:33 PM	Altium Schematic ...	236 KB
MicroProcessor K21	5/28/2015 11:52 A...	Altium Schematic ...	236 KB
Power Proto	5/28/2015 8:33 PM	Altium Schematic ...	189 KB
Power	5/28/2015 1:56 PM	Altium Schematic ...	190 KB
User Buttons Proto	5/28/2015 8:33 PM	Altium Schematic ...	121 KB
User Buttons	5/28/2015 11:47 A...	Altium Schematic ...	121 KB
XBee Wifi Proto	5/28/2015 8:33 PM	Altium Schematic ...	38 KB
XBee Wifi	5/28/2015 11:53 A...	Altium Schematic ...	38 KB

Figure 10: HAMS II Schematics w/ Libraries

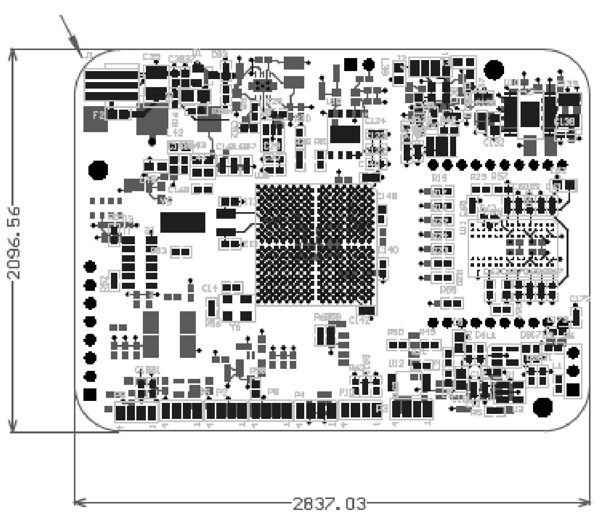


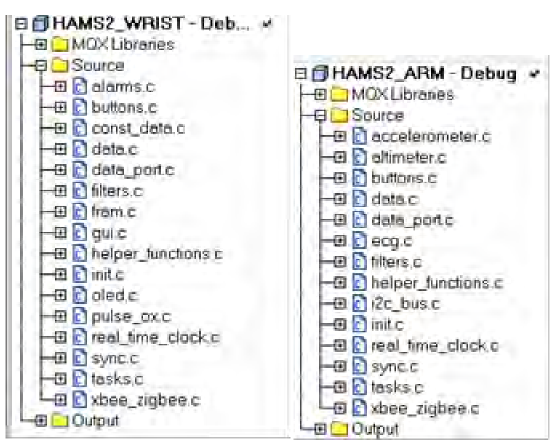
Figure 11: HAMS II: PCB

3.1.4 Software Functions and Design

As the specific hardware and microcontroller continue to be defined, updates will continue to develop on the draft Software Requirements Specification (SRS). This will drive the draft Software Design Description (SDD) that defines the software architecture and interfaces to hardware. These are living documents in the early phases of concept exploration and initial prototyping so we can capture the design as it is evolving.

Initial software workspace was developed into code modules scripted using the Freescale Tower System. Adjustments will need to be scripted for the actual processing of the raw data and transmitting the data to a receiver. Updates are listed below including C source files completed:

- Wrist firmware and Arm firmware
  - Project workspace created
  - Code files created for each module
  - Most code modules are at least 75% written and need to test
  - Project currently runs on the development board
- Ear firmware
  - Not started
  - Most code modules will be directly copied from wrist and arm firmware



As the software workspace code modules were completed towards the end of this reporting period the focus was to develop the arm sensor firmware with an array of sensors and software processing. Initial software tests demonstrated limited memory from the K21 processor and limited data ports indicating a need to upgrade the hardware from K21 to K70. Adjustments will need to be conducted in the system libraries to update the use of a higher end processor and added DDR memory.

The custom Pulse Ox detector circuit was also developed and described in the sensor section of this document. Analog data was gathered and processed via initial software algorithm development. Two software modules were focused on this reporting period. Listed functions for the system prototype are shown in the table below. The code includes Pulse Rate and SpO2 functions. The Pulse Rate function reads the IR-IR Ambient data from the AFE custom circuit and calculates pulse rate based on the peak-to-peak time difference. The SpO2 function reads in Red, Red Ambient, IR, IR Ambient data and calculates SpO2. Functions to follow in future development activities will be respiratory rate, HRC, PWTT, pulse differential, and pulse character. These additional functions are also listed in Table 1 below.

- Arm firmware
  - Project workspace upgrade from K21 to K70
  - Code files were updated for each module
  - Updated processor code, further testing needed for performance and sensor data validation
  - Project currently runs on the development board

Function Prototype	Inputs	Outputs
float CalculateSpO2(float *redIn, float *redAmbientIn, float* irIn, float* irAmbientIn);	Red, Red Ambient, IR, IR Am	SpO2 in %
float CalculatePR(float *irMinusIrAmbientIn);	IR - IR ambient	PR in bpm
TBD CalculatePulseCharacter(float *irMinusIrAmbientIn);	IR - IR ambient	TBD
float CalculatePulseDifferential(float *irMinusIrAmbientIn1, float *irMinusIrAmbientIn2);	IR - IR ambient from 2 separ	time difference in mSec
float CalculateHR(float *ecgIn);	ECG	HR in bpm
float CalculateHRC(float *ecgIn);	ECG	1 number
float CalculateRR(float HR);	HR	RR in bpm
float CalculateCO(float *coIn);	CO	CO in ppm
unsigned char CalculatePosition(float *xIn, float *yIn, float *zIn);	X, Y, Z	orientation of user
unsigned char CalculateGLoad(float *xIn, float *yIn, float *zIn, float *gResultsArrayOut);	X, Y, Z	array of G loads and times
float CalculatePwtt(float *irMinusIrAmbientIn, float *ecgIn);	ECG, IR - IR ambient	PWTT in mSec
unsigned char CalculateDCP(TBD);	hr, pulse diff, pulse char	state, 0-5
float CalculateWorkload(float hr);	HR	workload, 0 - 100 %
float CalculateFatigue(float hr);	HR	fatigue, 0 - 100 %
float CalculateBlast(float *pressure);	Pressure	blast probability, 0-100%
unsigned char CalculateMurphyFactor(TBD ALL);	TBD ALL	MF, 0-5
float HamsPredict(float altitude, float *gResultsArray);	time at g, altitude	risk of hypoxia, 0 - 100%
float CalculateActivity(float *xIn, float *yIn, float *zIn);	X, Y, Z	0-100 % activity

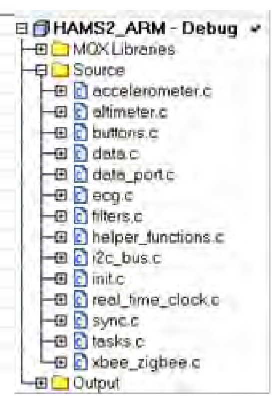


Table 1 Algorithm Functions.

3.1.5 Algorithm(s) Incorporation

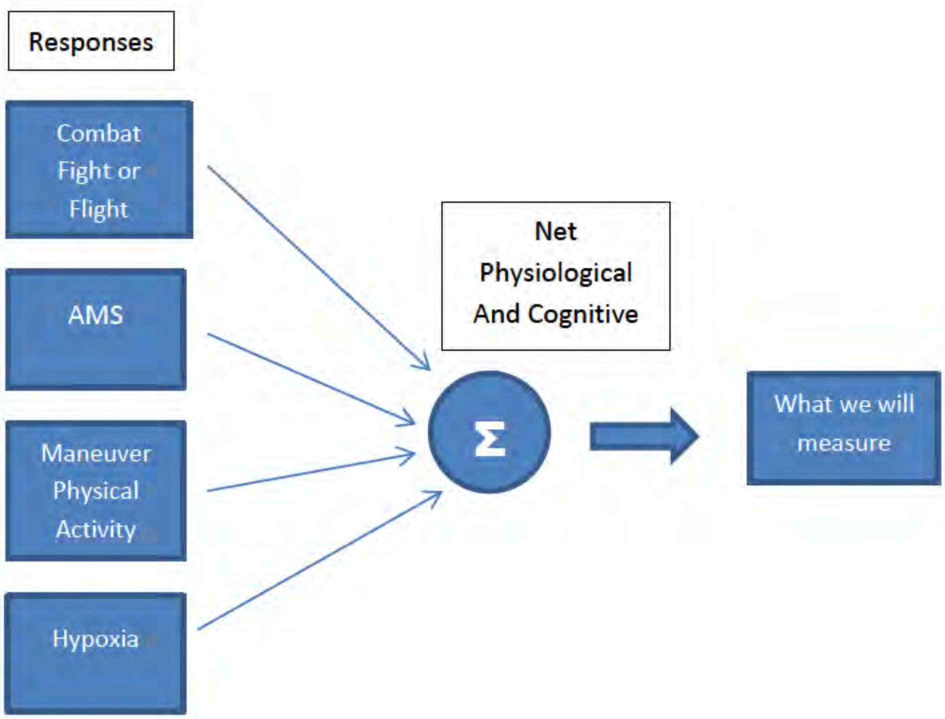
Project Review-Aerospace Medical Association Meeting

A project review was held before the start of the Aerospace medical Association Meeting in Orlando, FL on May 10, 2015. The meeting was conducted by Dr. Shender and attended by Cesar Gradilla and Sean Mahoney from Athena GTX, Phil Whitely from CAI, Dr. Leon Hrebien from Drexel, Dr. Moshe Kam from

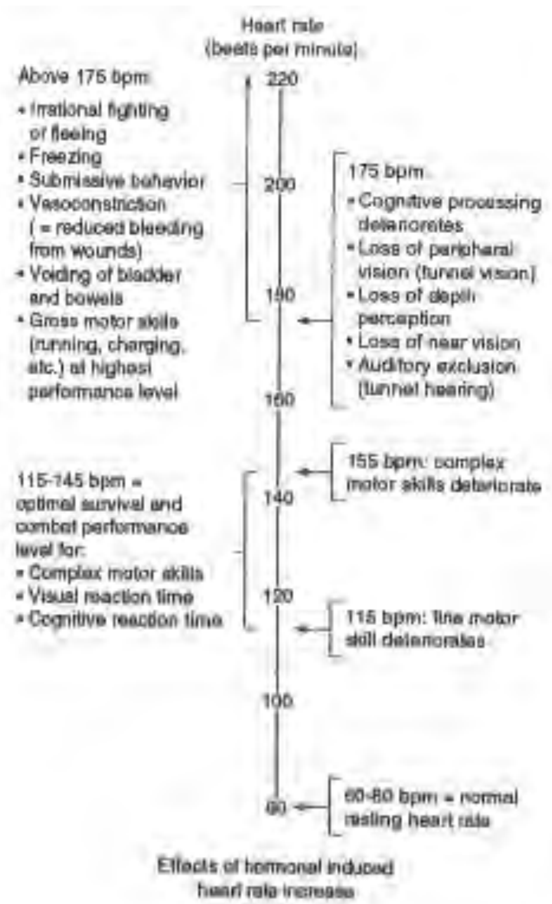
New Jersey Institute of Technology, and Dr. Khalid Barazanji who is an Army interested party from USAARL and is the Branch Chief of Airworthiness Certification and Evaluation.

Operator State during Mountain Operations

One of the central goals of the technical lead is to develop a metric or method to determine the cognitive decline during mountain missions attributed presumably to altitude hypoxia. While we are measuring physiological parameters and even if we could measure brain metabolism, those measurements must be placed in context of what is happening to the soldier during the mission especially during engagement with the enemy. The diagram below gives an overview of the various responses that are in play in the combat soldier.



Soldier physiological and cognitive capabilities are influenced by the typical flight-or-fight response, acute mountain sickness, the physical demands of maneuver and engagement and the environmental effect of hypoxia – perhaps more. The summation of these responses gives the net effect that will be reflected in the measurements the HAMS indicates. So if we are to identify a state of cognitive decline, this identification is more like a classification rather than a "trip wire" or the measurement of a key metric as technical lead desires. An example using heart rate is seen below in the boxed information on heart rate measured during a study of law enforcement officers during a paint ball simulation of conflict. The narrative is quoted directly from the internet webpage source. For example, the idea that measuring heart rate alone, without context of the event, may be meaningless unless we include some indication with correlation/classification of activity state through an actigraph/accelerometry measurement. While we may question the heart rate levels stated by work, likely due to motion artifact, the scale on the left may be more indicative of the activity we are up against when trying to predict a state of cognitive decline.



http://www.killology.com/art_psych_combat.htm

"**Humans have three primary survival systems: vision, cognitive processing, and motor skill performance.** Under stress, all three break down. Bruce K. Siddle's landmark research at PPCT involved monitoring the heart rate responses of law enforcement officers in interpersonal conflict simulations using paintball-type simulation weapons. **This research has consistently recorded heart rate increases to well over 200 beats per minute, with some peak heart rates of up to 300 beats per minute.** These were simulations in which the combatants knew that their life was not in danger. The combatant, in a true life-and-death situation (whether soldier or law enforcement officer), faces the ultimate universal human phobia of interpersonal aggression and will certainly experience a physiological reaction even greater than that of Siddle's subjects. The fundamental truth of modern combat is that the stress of facing close-range interpersonal aggression is so great that, if endured for months on end without any other means of respite or escape, the combatant will inevitably become a psychiatric casualty."

If we consider the effect of exercise under hypoxia on cognition, Ref [2] Ando et al. (2013) reported an <u>improvement</u> in cognitive function attributable to exercise and that hypoxia had no effect on cognitive function in their experiment condition. This group exposed 12 male subjects to altitude equivalents of 1,300 m (4265 ft) and 2600 m (8530 ft) on a cycle ergometer at 20% and 60% of peak VO_2 while performing the Go/No-Go task which requires recognition and response to a visual stimulus with percent correct and reaction time as metrics. While physiological parameters were significantly different during the various experimental phases where the average peak reported heart rate was 169 bpm during exercise at the highest altitude, the lowest average pulse oximetry value was ~83 and the average NIRS cerebral oxygenation value dropped 10% during exercise at the highest altitude. No significant differences in reaction time and response accuracy were found for any condition. These authors felt that exercise was a stimulant to cognitive function in the face of mild hypoxic conditions. Ref [4] Ogoh et al. (2014) reported that increasing middle cerebral artery blood flow, through hypercapnia and with and without performing cycle ergometer exercise at heart rates of 140 bpm, had no influence on cognitive performance measured through the Stroop Test. However these authors felt that improved cognitive function may be due to cerebral neural activation associated with exercise rather than global cerebral circulatory condition. So the stimulus effect of activity may be an underappreciated enhancer of cognitive performance. So far physical activity has been considered as an oxygen utilizer and detriment in hypoxia.

If we consider that the interest by the user community seems to be in state indication rather than evaluating numbers, we should work towards state specification and identification. We have states demarcated by combinations of activity, altitude, physiology (heart rate and oxygen saturation) and time. Altitude and time help to specify AMS state. Activity and time help to specify work rate. Heart rate and oxygen saturation help to specify physiological state. Heart rate combined with acceleration from actigraph measurements and BMI can be used to compute VO_2 .

$VO_2 = 4.735+0.0038*A+0.0063*HR^2 - 0.322*BMI$. (Ref [3] Moran, Heled, & Gonzalez, 2004)

When compared to max VO_2 as derived from a person's two-mile run an indication of personalized capacity state can be generated which can also be graded by altitude.

Ranges of these parameters on a time basis can be established, some already established for AMS, to develop the various state definitions which can be red, yellow and green indicators of state condition. Within the set of all states will lay the indictor of cognitive state which will be dependent on the combination of the other states. This approach does not require extensive computation but classification and combination. Classification can be as simple as range recognition and time tracking for duration. Combination may take a few approaches as simple as "if-then-else" decisions to crisp or fuzzy logic.

Altitude Chamber Data

The work reported for this period pertains to an analysis of the uploaded altitude chamber data from Dr. Shender.

Runs at 18,000 feet (18K) and 25,000 feet (25K) were uploaded. The associated protocol particulars are contained in the uploaded protocol. This report will focus on the Oxygen Saturation values, the composite scores during control, 10,000 feet (10K), 18K and 25K exposure periods, and the neurological model active node predictions to examine whether a five level score threshold approach can be adopted.

Figure 12 shows the oxygen saturation time history plots for all subjects during 18K altitude chamber exposures. Oxygen saturation decreases first at the 10K pre-exposure and then at the 18K level with a fairly broad response variance. Figure 13 shows the time point average across all subjects without regard for aligning peak response points. The average oxygen saturation level at 10K is 93% while at 18K the level is 79%.

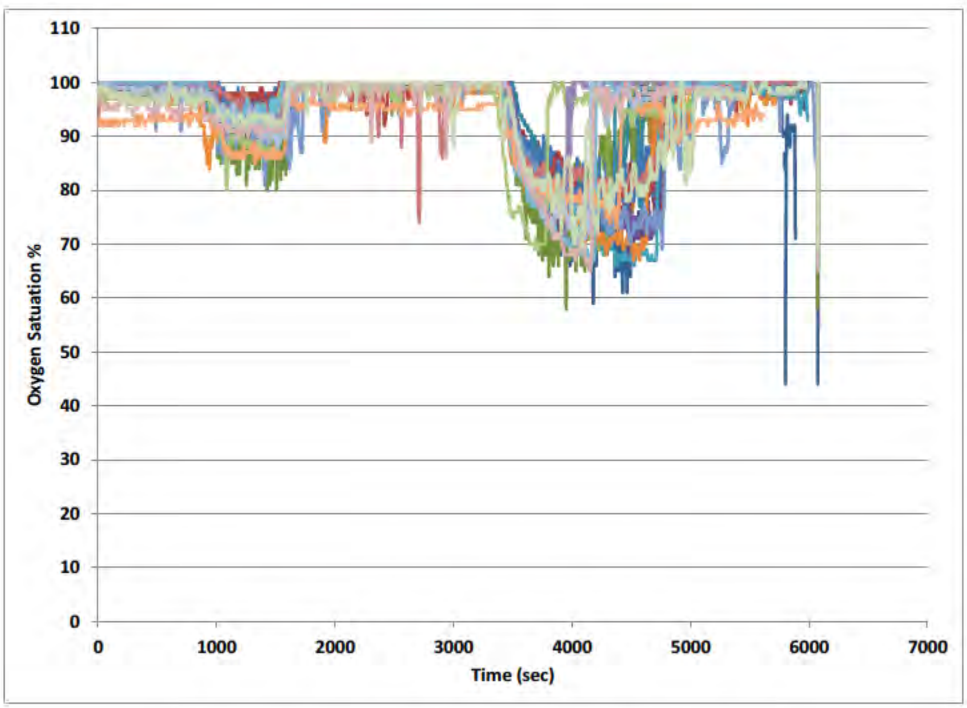


Figure 12 All Oxygen Saturation Data for 18K Exposures

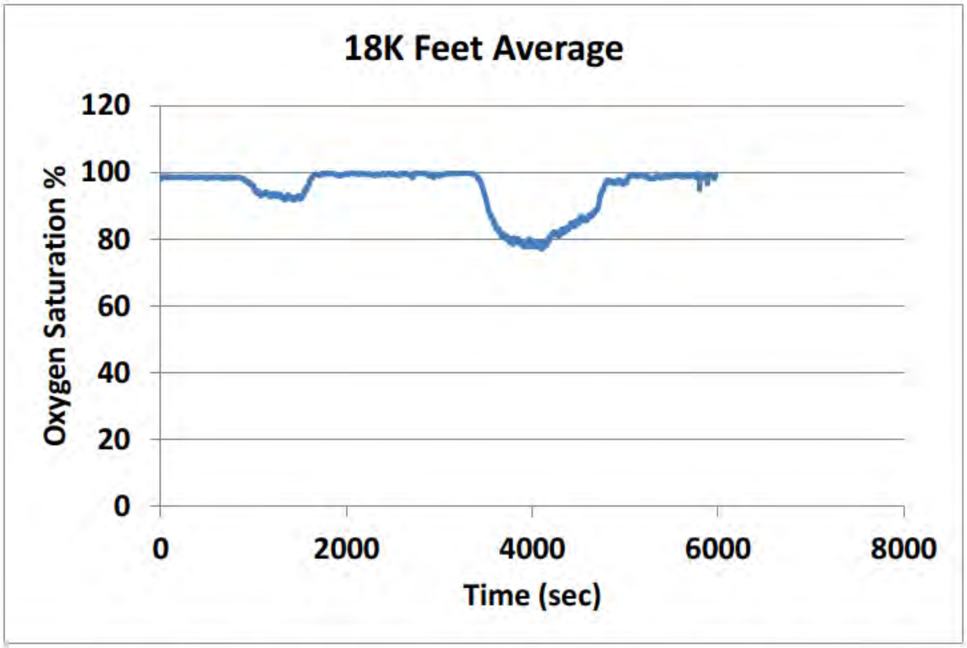


Figure 13 Group Average Oxygen Saturation for 18K Exposures

Figure 14 shows the oxygen saturation time history plots for all subjects during the 25K altitude chamber exposures. A similar response in noted at 10K as seen in the 18K runs, but the 25K exposure seen in this figure shows greater decrease in oxygen saturation and shorter exposure times due to run termination. A later response is seen where one subject's maximum oxygen saturation loss was delayed 200 seconds compared to other subjects. Figure 15 shows the time point average across all subjects without regard for aligning peaks. While the 10K average oxygen saturation decrease was similar to the other runs at 93%, the average oxygen saturation during the 25K exposure was 75% which is not appreciably different than the 18K level with this average approach.

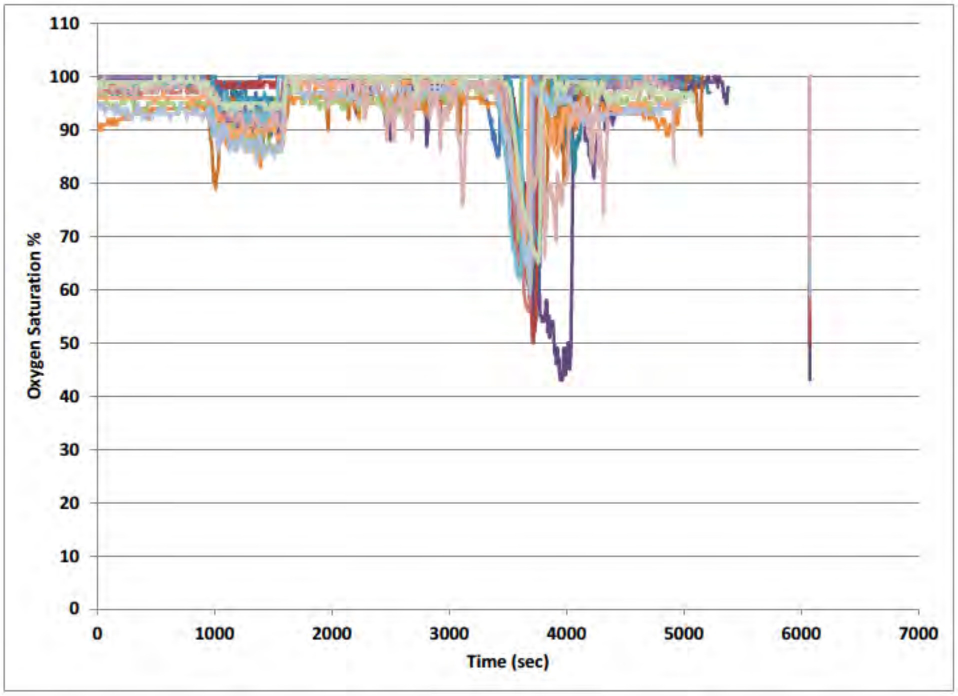


Figure 14 All Oxygen Saturation Data for 25K Exposures

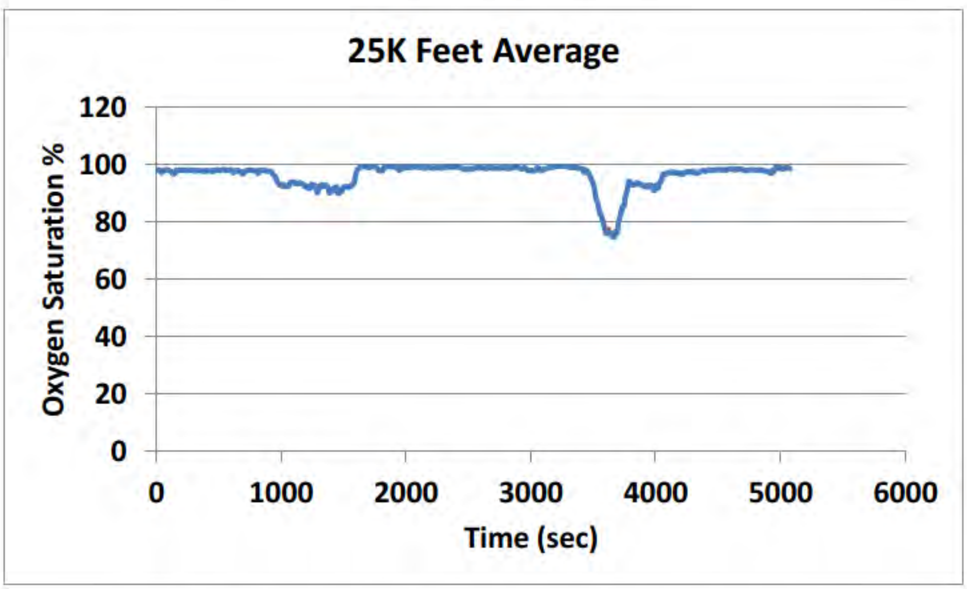


Figure 15 Group Average Oxygen Saturation for 25K Exposures

Measuring the maximum tangential oxygen saturation decline slope from the average oxygen saturation plots for 18K and 25K feet excel plots, the maximum slope for 25K was -0.151 %SaO2/sec and -0.0851 %SaO2/sec for 18K. The 25K oxygen saturation decline slope was about twice that for 18K. So for the oxygen saturation to drop 30 points at 18K and 25K, a 5.9 and 3.3 minute exposure would be required on average, respectively.

The composite score from the performance task was evaluated over the exposure period as indicated in the data spreadsheet using a t-test to compare levels. Table 2 and Table 3 show the percentage of significantly different composite score t-tests at each comparison condition. For the 18K chamber series in Table 2, there were no significantly different comparisons from ground (GND) to 10K but for GND to 18K 38% of the comparison were significant and for 10K to 18K exposures 24% of comparisons were significantly different.

Table 2 Percentage of t-tests significantly different for 18K.

Level Comparison	Significantly Different
Gnd to 10K	0%
Gnd to 18K	38%
10K to 18K	24%

Gnd – ground level, K – 1000 feet

During the 25K runs, shown in Table 3, 14% of the GND to 10K comparison were significantly different. Since the exposure was more physiologically significant, the comparisons between GND and 25K and 10K and 25K showed a higher percentage of significantly different comparisons at 68% and 73%, respectively.

Table 3 Percentage of t-tests significantly different for 25K.

Level Comparison	Significantly Different
Gnd to 10K	14%
Gnd to 25K	68%
10K to 25K	73%

Gnd – ground level, K – 1000 feet

The oxygen saturation time history data was evaluated using the neurological model by examining the Active Node results. Since unconsciousness would be rare in these exposures and the cluster value is directly related to the unconsciousness prediction, the Active Node value may be more appropriate for this global cerebral hypoxia event.

For the 18K exposures, not all runs were terminated. Separating the terminated from the non-terminated runs provides a convenient comparison for the Active Node value. All subject runs were used versus combining repeat runs since we were using the binary indication of termination.

Figure 16 shows the Active Nodes in non-terminated runs at 18K. A broad spectrum of response is observed where the variation is due to the oxygen saturation value variation.

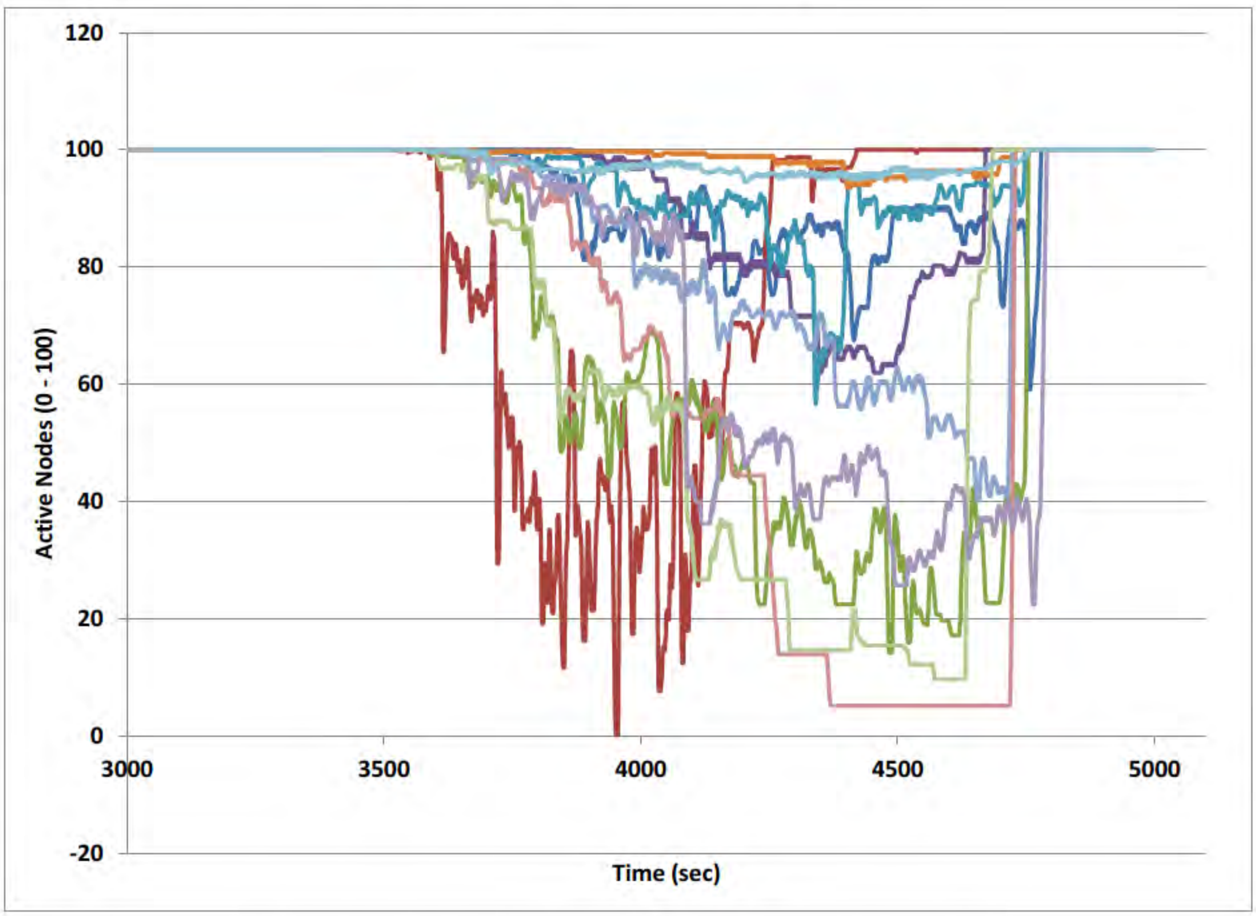


Figure 16 Active Node Results for Non-Terminated Subject Runs at 18K

Figure 17 shows the Active Nodes in terminated runs at 18K. While a broad spectrum of response is also observed, more runs have lower Active Node values subjectively.

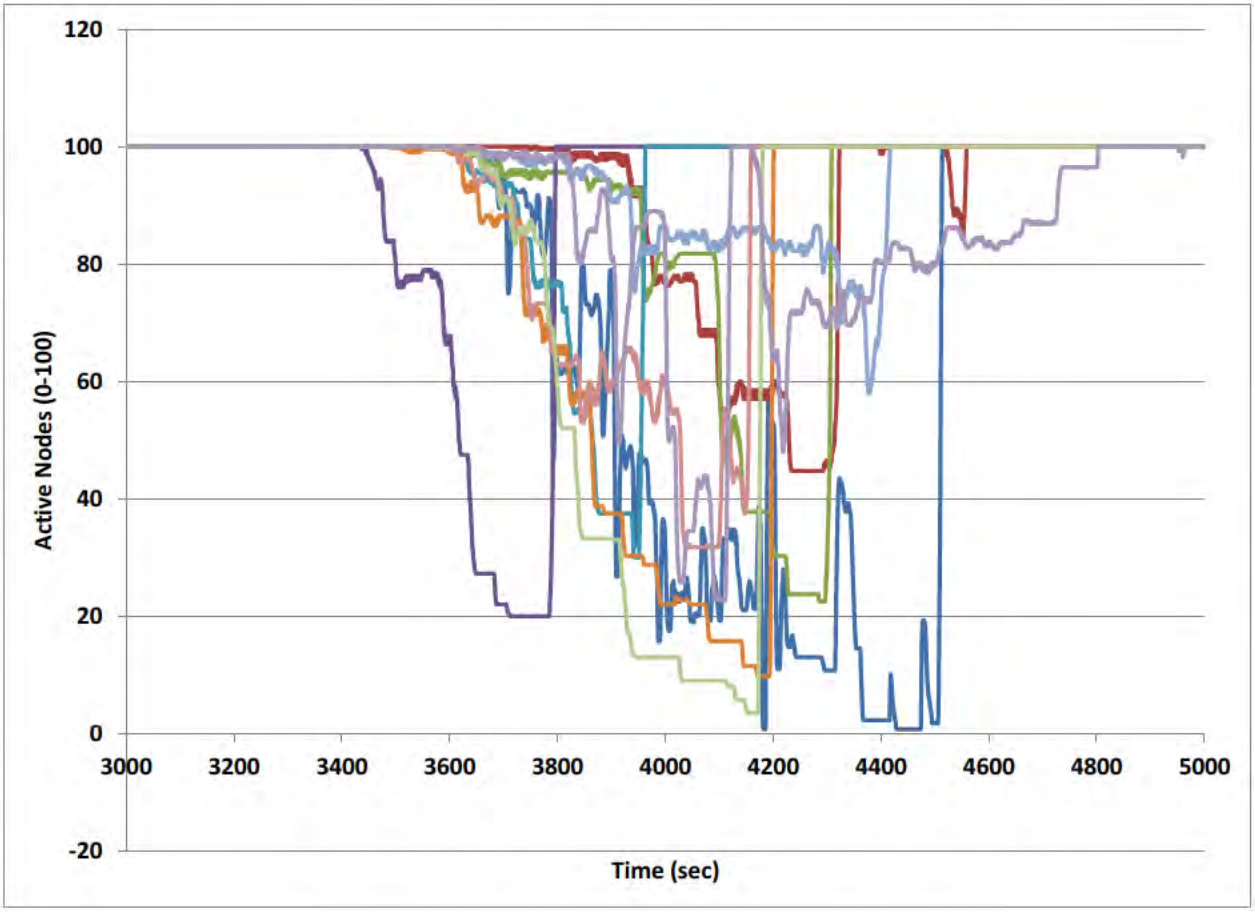


Figure 17 Active Node Results for Terminated Subjects at 18K

Figure 18 shows the Active Nodes in terminated runs (all runs were terminated) at 25K. The Active Node values "bottom out" at zero for several subjects where the physiological stress of the higher altitude is evident.

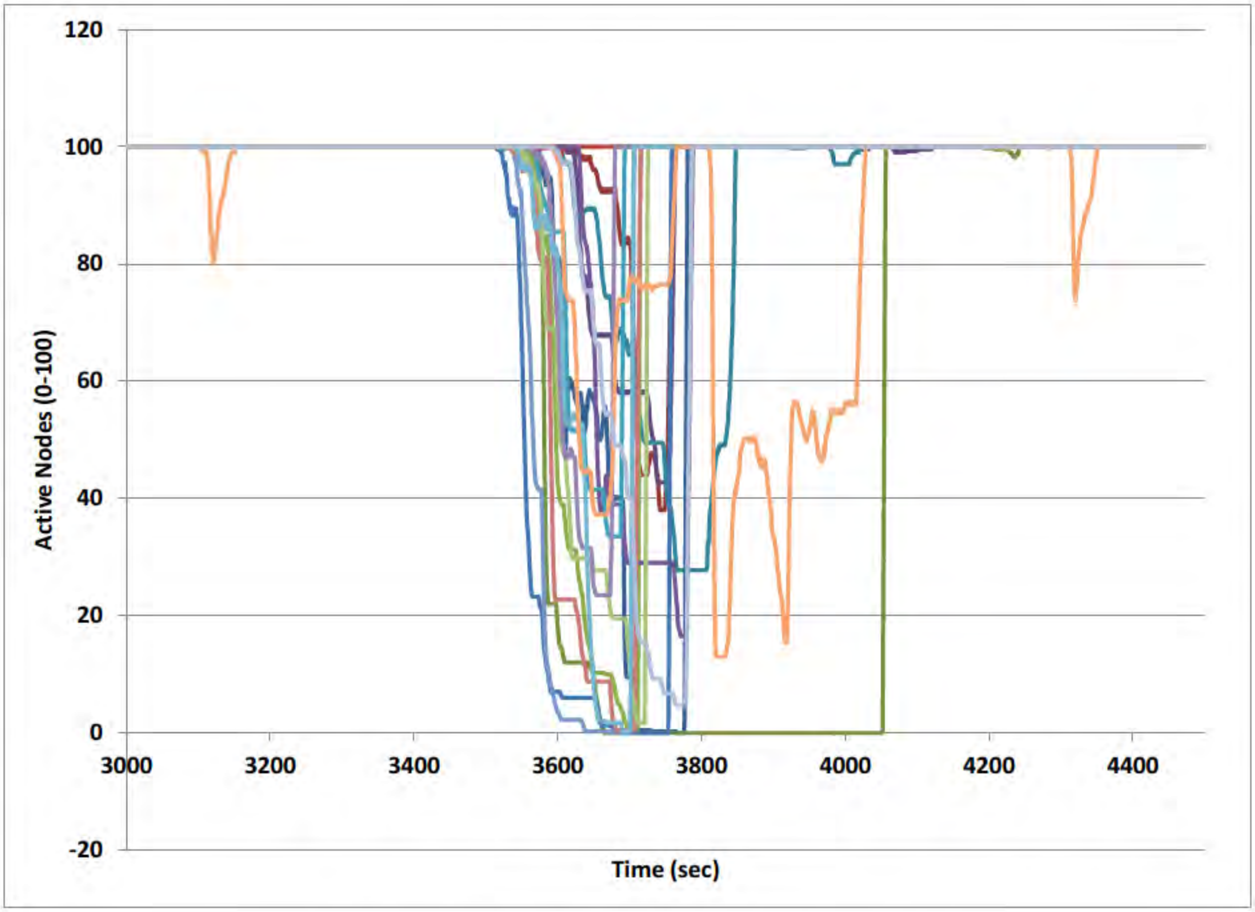


Figure 18 Active Node Results for Terminated (All) Subjects at 25K.

The non-terminated and terminated predictions at 18K along with the 25K prediction for Active Node were analyzed for mean and standard deviation with the results shown in Figure 19 through Figure 21. For all cases the 10K exposure did not cause any decrease in Active Node value and additionally the standard deviation at a non-stressed state was near zero. Only during the altitude stressor did the population variance become evident. Given the large standard deviations observed in these time histories, distinguishing a terminated versus non terminated state would seem impossible on a population response basis. Table 4 shows the minimum average Active Node value along with +/- one standard deviation for that minimum average value. Considerable overlap is seen which supports the concern that reliably hard separations for states are not available unless perhaps calibrated by person.

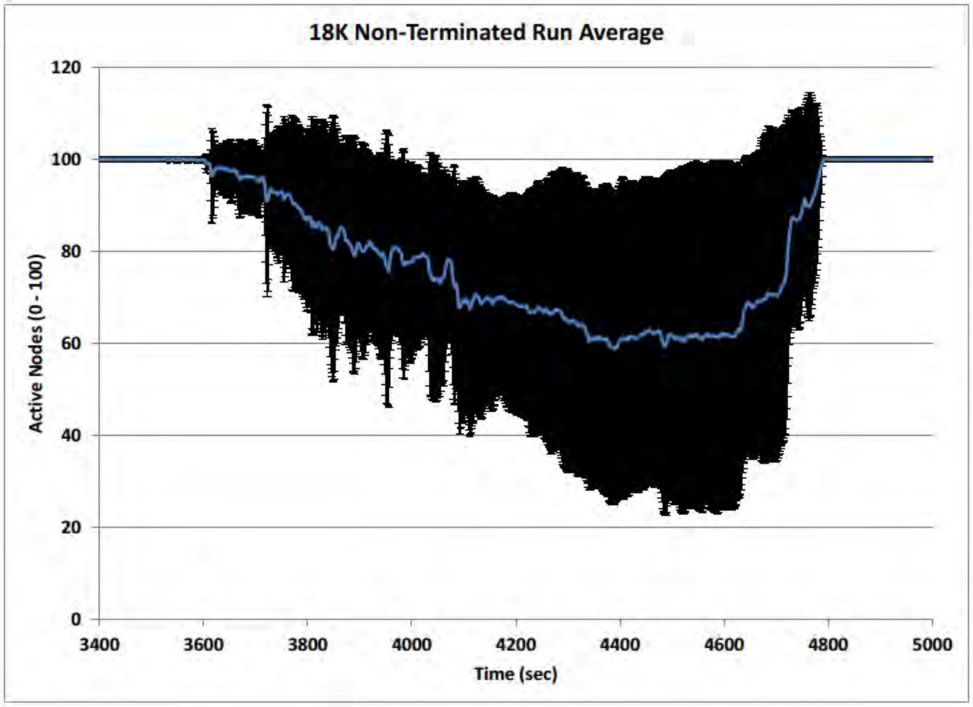


Figure 19 Active Node Run Average for Non-Terminated Subjects at 18K

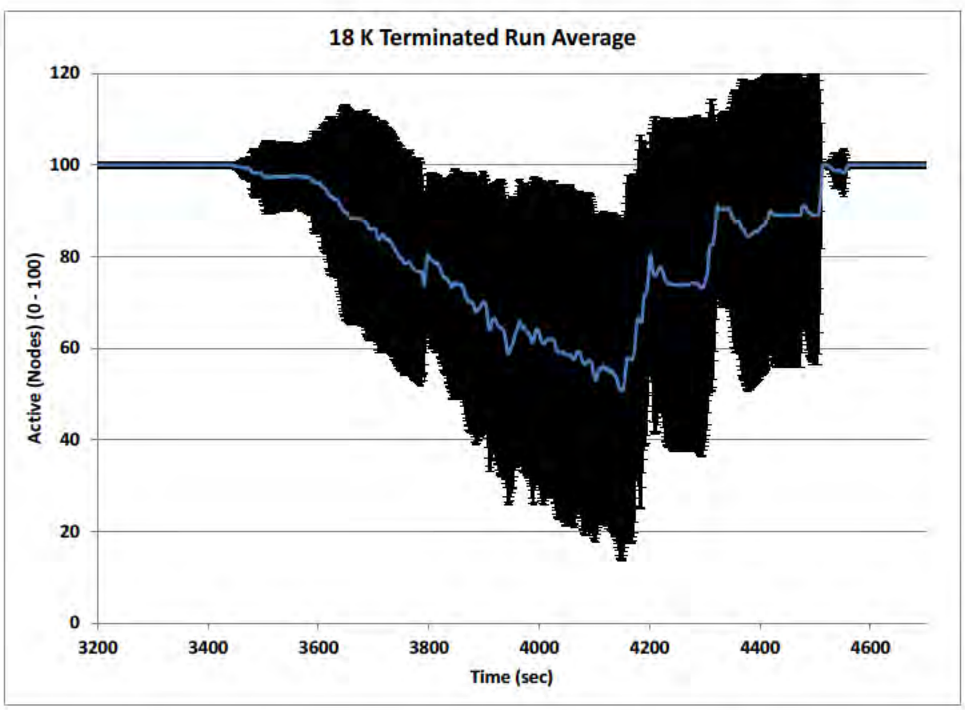


Figure 20 Active Node Run Average for Terminated Subjects at 18K

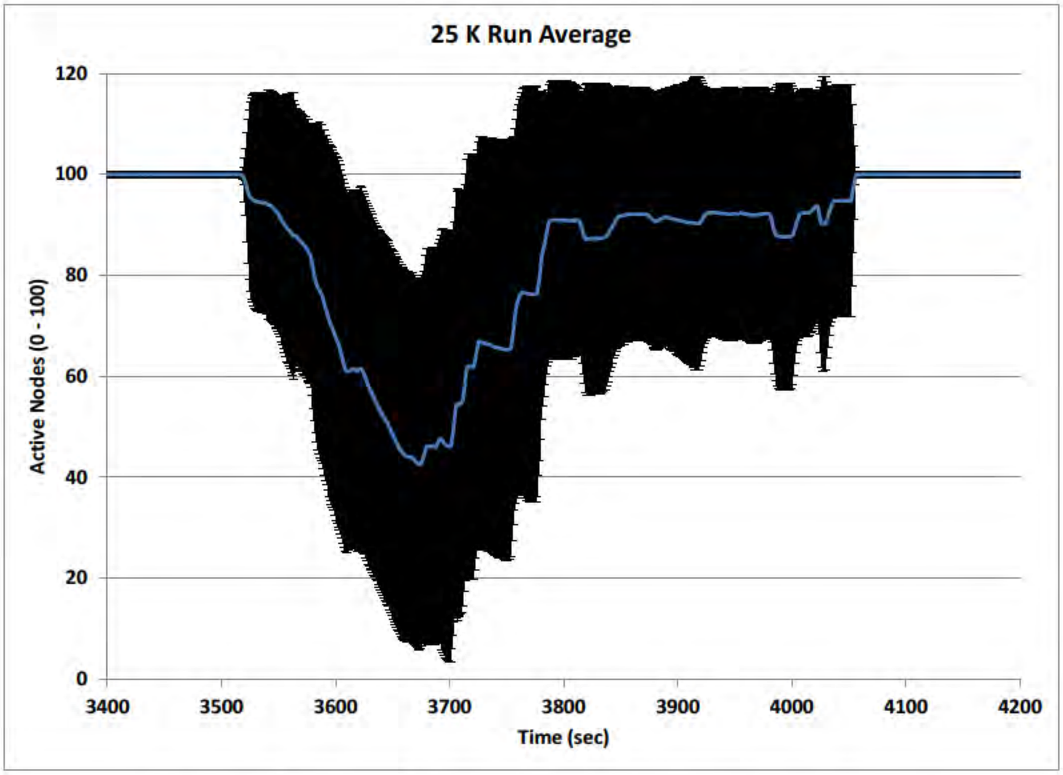


Figure 21 Active Node Run Average for Terminated (All) Subjects at 25K

Table 4 Range of Minimum Average Active Node Values by Condition

Condition	Minimum Average Active Node	+ 1 Standard Deviation	– 1 Standard Deviation
Non-Terminated 18K	59	92	26
Terminated 18K	51	88	14
Terminated 25K	45	81	9

The scope of observation to include the GND and 10,000 feet Active Node results are expanded in Figure 22 along with the predicted percentage of arterial oxygen saturation for that altitude. If a 5-level approach is taken in 20 unit intervals, one can see in Table 5 that a function indication can be developed along the lines of response that at Active Node levels of 100-80, subjects are mostly functional, at 80-60 some subjects are marginal where they demonstrate a decline in performance, between 60-40 subjects experience impairment induction where some are impaired and runs are terminated and others a potentially marginal, between 40-20 most subjects could be impaired and are military function would be compromised, and lastly between 20 and 0 response would indicate a critical physiological level where subject are non-functional. These levels could be indicated by a color code as shown in the table where at Level the indicator light would flash and/or a tactile indicator energized at Levels 4 and 5. The actual colors would depend on the color availability but these are consistent with hazard indications.

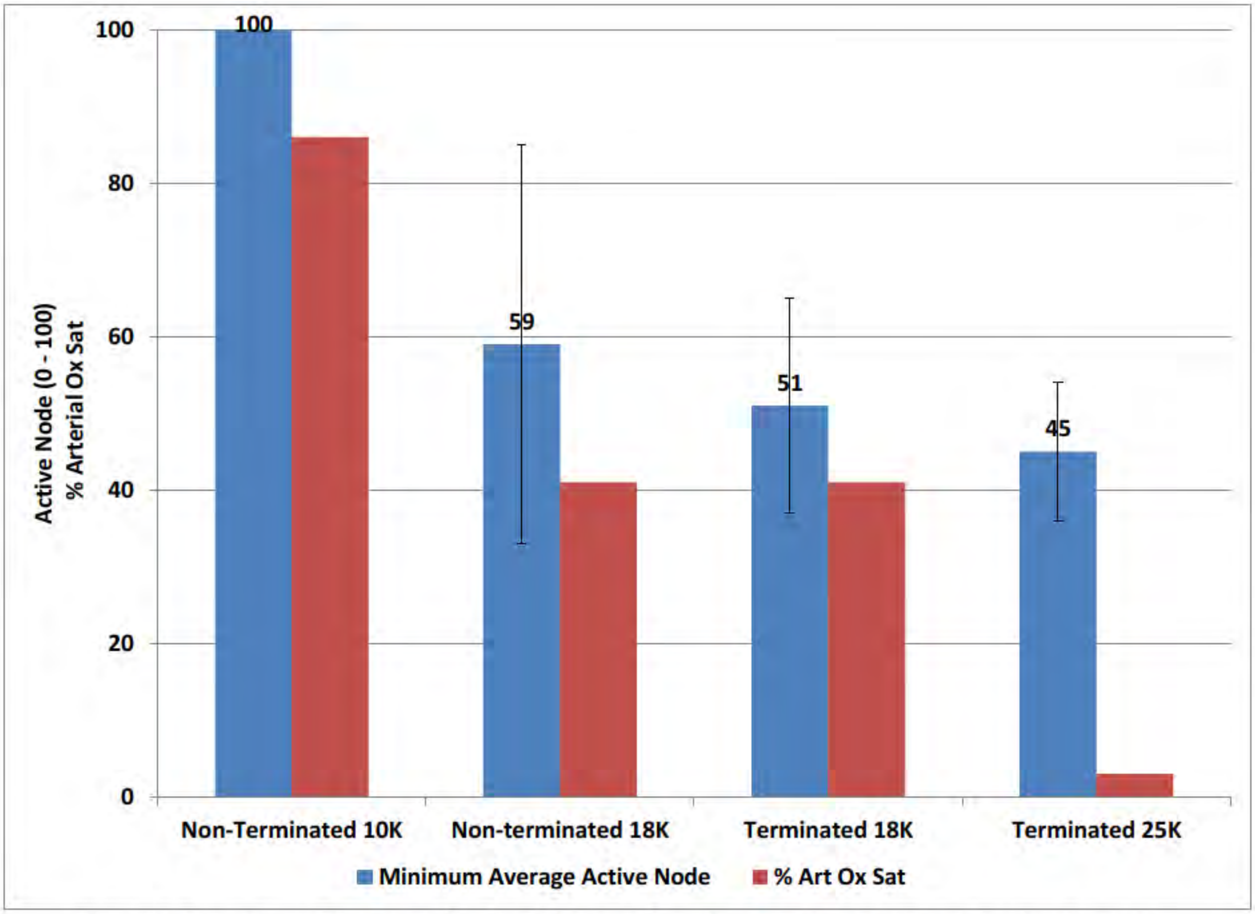


Figure 22 Comparison of Average Active Node Values by Condition and Arterial Oxygen Saturation Percentage

Table 5 Potential Indicator Scheme for Active Node Predictions

Active Node Level	Level	Indication	Color Code
100-80	1	Functional	
80-60	2	Marginal	
60-40	3	Impairment Induction	
40-20	4	Impaired	
20-0	5	Critical	

This 5-level approach is not terribly creative but would seem to cover the necessary ranges for indication. One could take a 2-level approach where an Active Node value of 50 would be the divider for "OK" or "Not OK". The 5-level approach could be enhanced by establishing a probability of a value being in a level using an arbitrary standard deviation or establishing a standard deviation over time. Instead of a probability one could use a membership function to establish membership using an arbitrary function about an Active Node value which would establish membership in a Level. These alternative approaches help recognize the variance in the population data which may not be the case in an individualized approach. Given the need of field personnel to make quick decisions, the probability or membership function approach may be too much information where a single state indicator may be sufficient.

Observations

The oxygen saturation data time histories have been combined which may hide some effects since individuals reacted in different ways plus if their run was terminated the duration was shortened. However to get some indication of peak decrease in Oxygen Saturation for an exposure and a potential sorting out of terminated versus non-terminated, combination was necessary. The oxygen saturation measurement is technologically truncated as the SaO_2 falls to a particular low level where it may be unreliable which delimits the full scale. While the absolute oxygen saturation levels may not clearly indicate state separation at the two test altitudes, the rate of SaO_2 decrease on onset of the event may be more indicative of the impact of a sudden event. Given noisy SaO2 data, calculating a rate in the field may just produce a metric with even greater variance. Still the question arises if the change in oxygen saturation at levels of mountain operations will be sufficient to discern state if one uses a population basis. Such discernment was possible but not uniformly possible for 18K and 25K. The functional response decline at an operational ground combat altitude of 15,000 feet may be difficult to differentiate from sea level or 10K. Personalization may be indicated for these altitudes to enhance differentiation of state.

3.1.6 Initial User's Manual

No new activity in this reporting period.

3.1.7 Fabricate Prototypes

No new activity in this reporting period.

3.1.8 Test Prototypes for Delivery

No new activity in this reporting period.

3.1.9 Deliver Initial Prototypes

No new activity in this reporting period.

3.1.10 Test & Evaluation Support

This task has not been started.

3.2 Task 2 – Design and Development Evolution

This task has been started and overlaps the end of Task 1. We have begun to gather lessons learned from Task 1 in order to guide development of the preliminary prototypes.

3.2.1 Design Definition

This task has not been started.

3.2.2 Preliminary Design 1

This task has not been started.

3.2.3 Preliminary Design 2

This task has not been started.

3.2.4 Fabricate Prototypes

This task has not been started.

3.2.5 Test Prototypes for Delivery

This task has not been started.

3.2.6 Deliver Preliminary Prototypes

This task has not been started.

3.2.7 Test & Evaluation Support

This task has not been started.

3.3 Task 3 (Option) – Production Ready HW/SW

This task has not been exercised.

3.4 Task 4 (Option) – Preliminary Human Testing of SpO2 Sensor and Electronics

This task has not been exercised. This task will be performed in conjunction with Task 2 development. It is included as an option because it requires human testing.

3.5 Task 5 (Option) – Final Human Testing of SpO2 Sensor and Electronics

This task has not been exercised. This task will be performed in conjunction with Task 3 development. It is included as an option because it requires human testing.

4.0 Financial Progress

The total base budget for the HAMS program is $1,985K plus an Option 1 of $905K, Option 2 of $49K and Option 3 of $47K. The contractually obligated amount in FY2014 towards the total budget is $298K. The contractually obligated amount in FY2015 towards the total budget is $1,252K. Costs incurred to date through this performance period are $298K or 100% of the FY14 obligated funding and $336K or approximately 27% of the FY15 obligated funding.

The tables below summarize the costs incurred to date against the FY 2014 and FY 2015 obligated funding to date ($298K and $1,252K, respectively). A more detailed spread sheet has been included in the Appendix, Section 9.1.

4.1 *FY2014 Funding ($298K)*

Month	HAMS Projected (%)	ONR Benchmarks FY14 Funding (%)	HAMS Actual (%)	Benchmark Delta (%)	Comments
SEP-OCT	25	58	34	-24	
NOV	50	63	54	-9	
DEC	75	68	72	+4	Additional funding received on DEC 12, 2015.
JAN	100	73	100	+27	

4.2 *Benchmarks for FY2015 Funding ($1,252K)*

Month	HAMS Projected (%)	ONR Benchmarks FY15 Funding (%)	HAMS Actual (%)	Benchmark Delta (%)	Comments
JAN	1	6	1	-5	Additional funding received on JAN 15, 2015
FEB	5	12	5	-7	
MAR	15	20	11	-9	Additional funding received on MAR 5, 2015. Actual and Benchmark delta % were recalculated.
APR	17	23	15	-8	
MAY	23	29	21	-8	
JUN	29	35	27	-8	

5.0 Schedule and Deliverables

5.1 Schedule

Tasks / Milestones	FY 2015											
	CY 2014			CY 2015								
	O	N	D	J	F	M	A	M	J	J	A	S
1. Initial Prototypes												
2. Design and Development Evolution												
3. (Option) Production Ready HW/SW												
4. Human Testing SpO2 sensor (Option)												
5. Human Testing SpO2 sensor (Option)												
Milestones / Deliverables												
Monthly Updates												
Quarterly Reports												
Initial Prototypes												
Preliminary FDA Compliance Review												

Progress/Completed
Planned

Tasks / Milestones	FY 2016											
	CY 2015			CY 2016								
	O	N	D	J	F	M	A	M	J	J	A	S
2. Design and Development Evolution												
4. Human Testing SpO2 sensor (Option)												
Milestones / Deliverables												
Monthly Updates												
Quarterly Reports												
IDR												
PDR												
PCDR												
Final Report												
Preliminary Prototypes												

Tasks / Milestones	FY 2017											
	CY 2016			CY 2017								
	O	N	D	J	F	M	A	M	J	J	A	S
2. Design and Development Evolution	■											
3. (Option) Production Ready HW/SW		■	■	■	■	■	■	■	■	■	■	■
5. Human Testing SpO2 sensor (Option)							■	■				
Milestones / Deliverables												
Monthly Updates	■	■	■	■	■	■	■	■	■	■	■	■
Quarterly Reports	■			■			■			■		
Final CDR		■										
Formal Test Devices (5) Complete						■						
Verification Design Review												■

Tasks / Milestones	FY 2018											
	CY 2017			CY 2018								
	O	N	D	J	F	M	A	M	J	J	A	S
3. (Option) Production Ready HW/SW	■	■	■	■	■	■	■	■	■			
Milestones / Deliverables												
Monthly Updates	■	■	■	■	■	■	■	■	■			
Quarterly Reports	■			■			■					
FDA 510(k) Submission			■									
Validation Design Transfer Review					■							
FDA Clearance Determination						■						
Final Design Review									■			
Deliver Final Test Units									■			

Progress/Completed
Planned

5.2 *Deliverables*

5.2.1 Monthly Updates

The following monthly reports have been submitted to ONR for this reporting period:

- A003-03 HAMS II Monthly Update – DEC 2014
- A003-04 HAMS II Monthly Update – JAN 2015
- A003-05 HAMS II Monthly Update – FEB 2015
- A003-06 HAMS II Monthly Update – MAR 2015
- A003-07 HAMS II Monthly Update – APR 2015
- A003-08 HAMS II Monthly Update – MAY 2015
- A003-09 HAMS II Monthly Update – JUN 2015

5.2.2 Quarterly Reports

The following quarterly reports have been submitted to ONR for this reporting period:

- A001-1, Report for the period September 30, 2014 to December 31, 2014
- A001-2, Report for the period January 1, 2015 to March 31, 2015
- A001-3, Report for the period of April 1, 2015 to June 30, 2015

5.2.3 Final Report

- A002 Not due until August 2016.

5.2.4 Initial Prototypes

- First initial prototype delivered to Dr. Shender.
- A004 Not due until July 2015.

5.2.5 Preliminary Prototypes

- A005 Not due until August 2016.

6.0 Conclusion

Sensor definition testing continued on the custom pulse-ox design. Additional refinement on the pulse rate and SpO2 algorithm development was also accomplished. The electronics and software development made significant adjustments to accommodate the upgrade from the Freescale K21 to the K70 processor. New circuit boards we designed and fabricated. The software code was modified. The upgrade increased processing power to handle additional communication/interface ports and processing of the waveform data.

Additional hypobaric chamber data was uploaded to the HAMS FTP site. The relationships between sea level, 10K, 18K and 25K were analyzed. The introduction of degradation assessment categories was considered and discussed based on the Active Node prediction function output from the conscious model.

A project review was held before the start of the Aerospace medical Association Meeting in Orlando, FL on May 10th, 2015. The meeting was conducted by Dr. Shender and attended by Cesar Gradilla and Sean Mahoney from Athena GTX, Phil Whitely from CAI, Dr. Leon Hrebien from Drexel, Dr. Moshe Kam from New Jersey Institute of Technology, and Dr. Khalid Barazanji who is an Army interested party from USAARL and is the Branch Chief of Airworthiness Certification and Evaluation.

7.0 Recommendations

We recommend that the program continue as scheduled.

8.0 References

[1] Karinen, H. M., Uusitalo, A., Vähä-Ypyä, H., Kähönen, M., Peltonen, J. E., Stein, P. K., Tikkanen, H. O. (2012). Heart rate variability changes at 2400 m altitude predicts acute mountain sickness on further ascent at 3000-4300 m altitudes. Frontiers in Physiology, 3 AUG (August), 1–7. doi:10.3389/fphys.2012.00336.

[2] Ando, S., Hatamoto, Y., Sudo, M., Kiyonaga, A., Tanaka, H., & Higaki, Y. (2013). The effects of exercise under hypoxia on cognitive function. PloS One, 8(5), e63630. doi:10.1371/journal.pone.0063630.

[3] Moran, D. S., Heled, Y., & Gonzalez, R. R. (2004). Metabolic rate monitoring and energy expenditure prediction using a novel actigraphy method. Medical Science Monitor : International Medical Journal of Experimental and Clinical Research, 10(11), MT117–T120.

[4] Ogoh, S., Tsukamoto, H., Hirasawa, a., Hasegawa, H., Hirose, N., & Hashimoto, T. (2014). The effect of changes in cerebral blood flow on cognitive function during exercise. Physiological Reports, 2(9), e12163–e12163. doi:10.14814/phy2.12163.

9.0 Appendix

9.1 *Detailed Financial Spreadsheets (PDF)*

FUNDING

HAMS 2 FY 2014 - ACRN 000101-AA/000102-AB									
CONTRACT# N00014-14-C-0276									
Begins Sept 25, 2014 - Jan 31,	4+ months	ACTUAL EXPENDITURE % BY MONTH based on 298K		33.55%	54.05%	72.01%	100.00%	100.00%	100.00%
HAMS 2 FY 2014	CUMULATIVE SPENT FY14 FUNDS - BUDGET 1	REMAINING BUDGET	% of Total FUNDS Expended	MO 1 - SEP-OCT 2014	MO 2 - NOV 2014	MO 3 - DEC 2014	MO 4 - JAN 2015	MO 5 FEB	MO 6 - MAR
COST INCURRED	$ 298,679	$ (0)	100%	$ 100,199.76	$ 61,234.13	$ 53,650.29	$ 83,594.80	$ -	$ -
		HAMS 2 FY 20	BUDGET 1	MO 1 - SEP-OCT	MO 2 - NOV	MO 3 - DEC	MO 4 - JAN	MO 5 - FEB	MO 6 - MAR
BUDGET ACRN 000101-AA / 000102-AB			$ 298,679	$ 73,633.85	$ 75,254.92	$ 73,771.70	$ 76,018.10	$ -	$ -
			Projected expenditure % based on 298K budget	24.65%	49.85%	74.55%	100.00%	100.00%	100.00%
			Benchmark FY14	57.87%	63%	67.67%	73.02%	76.04%	81.40%

HAMS 2 FY 2015 - ACRN 000103-AC							
CONTRACT# N00014-14-C-0276							
Begins JAN 2015 - JUN 2015	4+ months	ACTUAL EXPENDITURE % BY MONTH based on 118,067		9.50%	55.08%	100.00%	100.00%
HAMS 2 FY 2015	CUMULATIVE SPENT FY15 FUNDS - BUDGET 2	REMAINING BUDGET	% of Total FUNDS Expended	MO 4 - JAN 2015	MO 5 - FEB 2015	MO 6 - MAR 2015	MO 7 - APR
COST INCURRED	$ 118,066.98	$ 0	100%	$ 11,216.61	$ 53,810.48	$ 53,039.90	$ -
		HAMS 2 FY 20	BUDGET 2	MO 4 - JAN	MO 5 - FEB	MO 6 - MAR	MO 7 - APR
BUDGET ACRN 000103-AC			$ 118,067	$ 14,192.55	$ 54,881.41	$ 48,993.07	$ -
			Projected expenditure % based on 118K budget	12.02%	58.50%	100.00%	100.00%
			Benchmark FY15	6.25%	13%	20%	23.03%

HAMS 2 FY 2015 - ACRN 000103-AD										
CONTRACT# N00014-14-C-0276										
Begins APR 2015 - AUG 2015	4+ months	ACTUAL EXPENDITURE % BY MONTH based on 327813		6.61%	22.16%	44.42%	66.54%	66.54%	66.54%	66.54%
HAMS 2 FY 2015	CUMULATIVE SPENT FY15 FUNDS - BUDGET 3	REMAINING BUDGET	% of Total FUNDS Expended	MO 6 -MAR 2015	MO 7 - APR 2015	MO 8 - MAY 2015	MO 9 - JUN 2015	MO 10 - JUL 2015	MO 11 - AUG 2015	MO 12 - SEP 2015
COST INCURRED	$ 218,129.21	$ 109,683	67%	$ 21,665.64	$ 50,987.28	$ 72,960.99	$ 72,515.29	$ -	$ -	$ -
		HAMS 2 FY 20	BUDGET 3	MO 6-MAR	MO 7 - APR	MO 8 - MAY	MO 9 - JUN	MO 10 - JUL	MO 11 - AUG	MO 12 - SEP
		BUDGET ACR	$ 327,813	$ 71,536.97	$ 17,094.67	$ 79,738.56	$ 77,684.88	$ 81,757.53	$ -	$ -
			Projected expenditure % based on 223K budget	21.82%	27.04%	51.36%	75.06%	100.00%	100.00%	100.00%
			Benchmark FY15	20.00%	23.03%	29%	35.15%	42.12%	49.07%	56.00%

10.0 List of Symbols, Abbreviations and Acronyms

3D	Three Dimensional
ADC	Analog to Digital Converter
AMS	Acute Mountain Sickness
BMI	Body Mass Index
bpm	Beats Per Minute
C	Programming Language
CAD	Computer Aided Design
CASEVAC	Casualty Evacuation
CDR	Critical Design Review
ECG	Electrocardiogram
FDA	Food and Drug Administration
FHP	Force Health Protection
ft	Feet
FTP	File Transfer Protocol
GND	Ground/Sea Level
HAMS	Hypoxia Monitoring, Alert and Mitigation System
HR	Heart Rate
HRC	Heart Rate Complexity
HW	Hardware
IDR	Initial Design Review
K	Thousand
m	Meters
max	Maximum
NIRS	Near Infrared Spectroscopy
ONR	Office of Naval Research
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PWTT	Pulse Wave Transit Time
SaO2	Arterial Oxygen Saturation Measured via CO-Oximeter
SDD	Software Design Description

sec	Seconds
SpO2	Arterial Oxygen Saturation Measured via Pulse-Oximeter
SRS	Software Requirements Specification
SW	Software
TI	Texas Instruments
uPROC	Micro-Processor
USAARL	United States Army Aeromedical Research Laboratory
USB	Universal Serial Bus
VO2	Oxygen Consumption
ZigBee	Wireless Protocol

11.0 Distribution List

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